

Joint EC/IAEA Training course with Nucleonica , 12-15th Oct., Monaco

RANGE AND STOPPING POWER CALCULATIONS IN NUCLEONICA

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Range & Stopping Power in Nucleonica

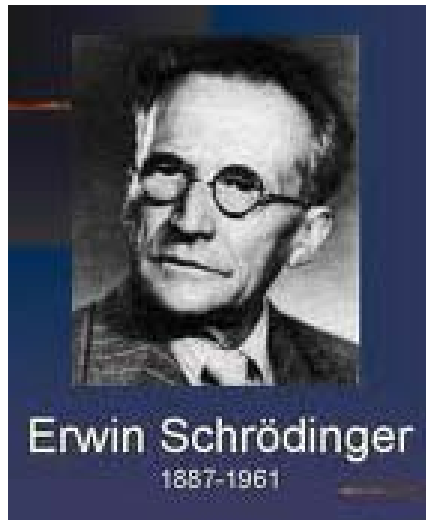
Stopping Power; energy loss of energetic particles per unit length in matter.

The range; the mean path length of the particle in the target matter before coming to rest.



Niels Bohr
(1885-1962)

The first calculation of stopping power was done by Bohr in 1913.



Wave mechanics started in 1926



Hans A. Bethe
1906-2005

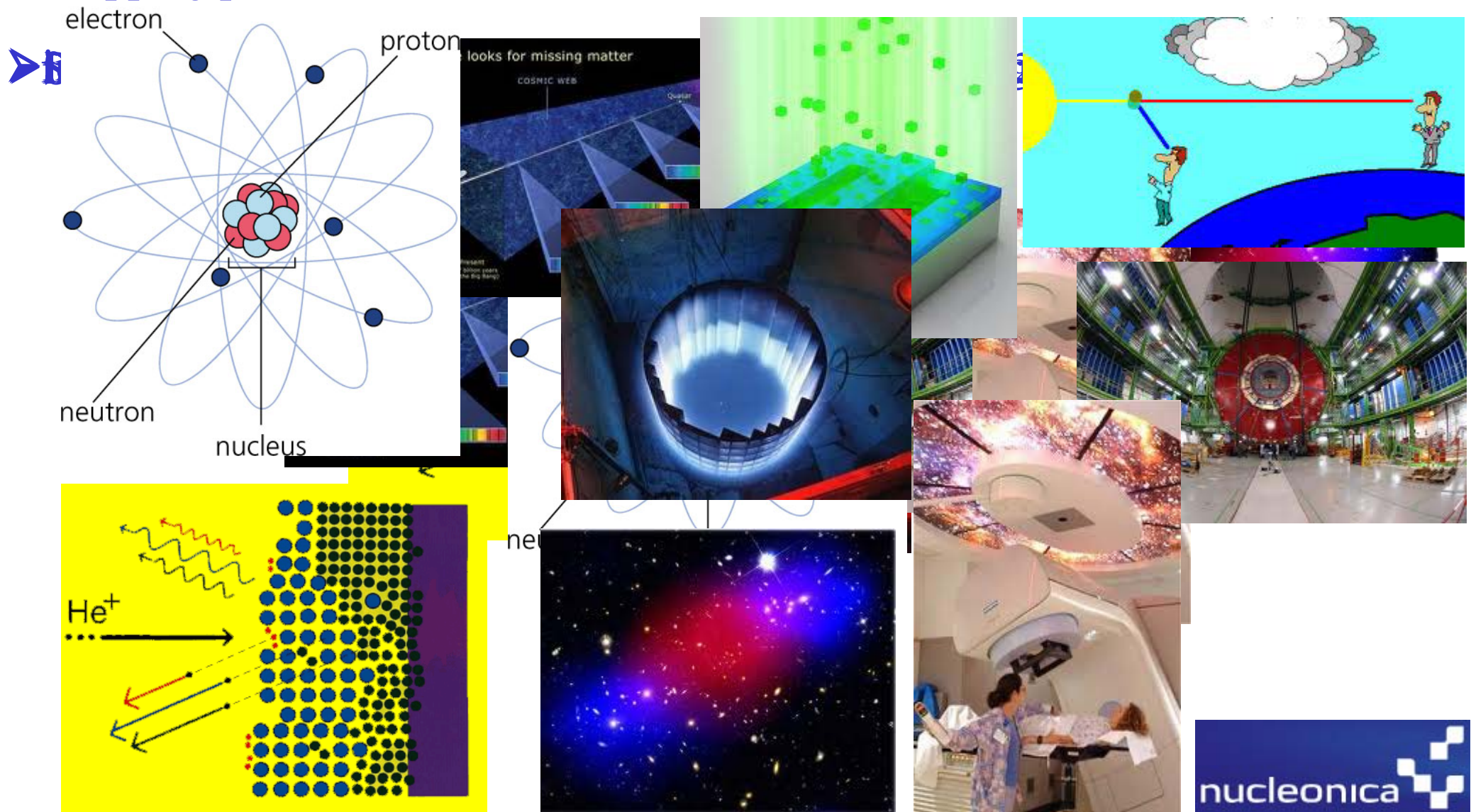
First quantum mechanical calculation of stopping power in 1930

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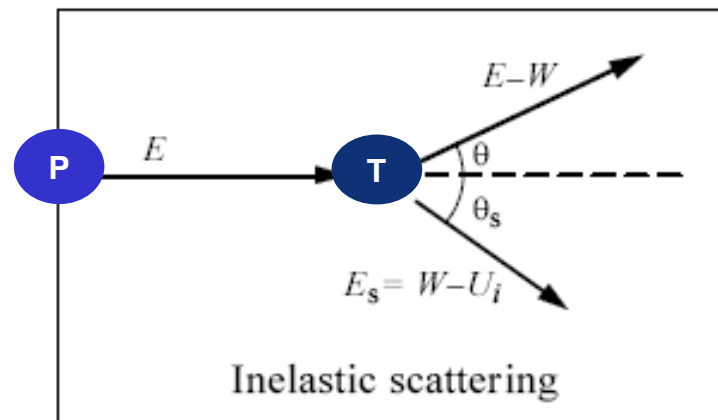
Stopping power has been studied



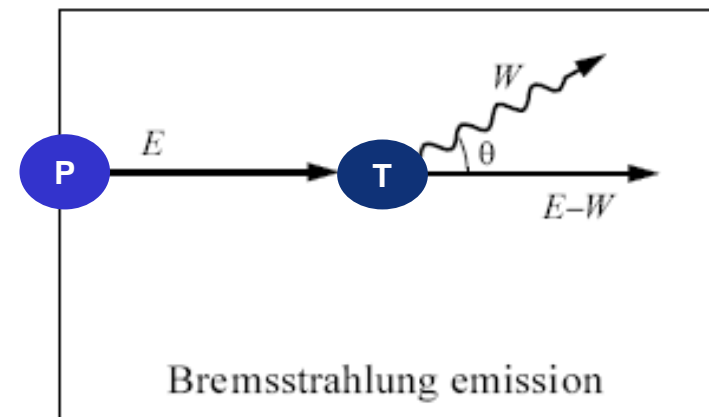
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Types of Interactions

- I. **Inelastic scattering on atomic orbital electrons.**
It leads to excitations and ionizations of atoms of the medium, and is called “**Collisional Stopping Power**”.



- II. **Inelastic nuclear scattering.**
This results in radiation which is known as “Bremsstrahlung”, so the stopping power is the “**Radiative Stopping Power**”.



Range & Stopping Power in Nucleonica

Physics Behind the RANGE Module

- The RANGE module uses the SRIM "engine" for heavy ions, alphas and protons.
- Own codes for the calculations for electron, positron and muon projectiles.
- The interaction of incident electrons with target electrons can be calculated from Bethe's theory.
- The collisional stopping power of matter is calculated by considering the effective charge approximation.
- For Radiative Stopping Power, RANGE module uses simple ratio:

$$S_{\text{rad}}/S_{\text{coll}} = ZE/800$$

- Range of the electrons, positrons and muons in matter is calculated by using Continuous Slowing Down Approximation (CSDA):

$$R(E) = \int_{E_{\text{abs}}}^E \frac{dE'}{S(E')}$$

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Projectiles

Main Interface:

Target

Test Results for Alphas

In this section, we give the results of stopping power and ranges for alphas in H (gas), Pb (solid) and water (liquid). We have compared the results for RANGE module with those from ASTAR. Obtained results are shown in the figs 7-12 for these targets.

Alphas in H (Gas)

Calculated results are shown in fig. 7 for stopping power and in fig. 8 for range. We have also given the mean errors in tables (see figs 9-12) for stopping power and for range, respectively.

Figure 7: The stopping power results for alphas on H (Gas).

Figure 8: The range results of alphas on H (Gas).

Compound composition

Z	Element	Atomic Weight	Stoichiometry	Atom %
3	Lithium	6.941	1	50
9	Fluorine	18.998	1	50

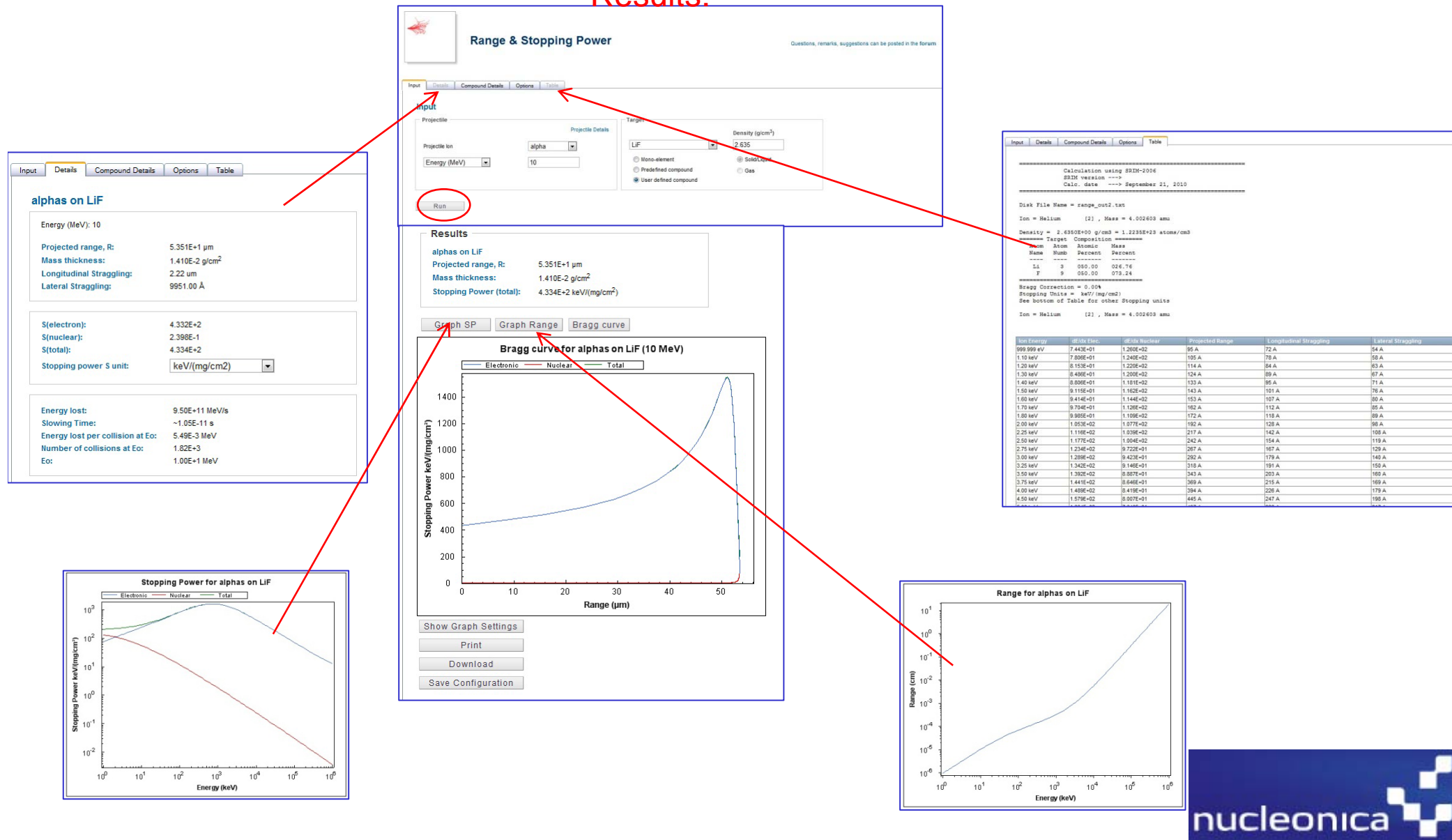
Wiki Help at
[http://www.nucleonica.net/wiki/index.php/Help:Range %26 Stopping Power](http://www.nucleonica.net/wiki/index.php/Help:Range%26StoppingPower)

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Results:



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Wiki Help:

Range Calculations

Most of the transport calculations and Monte Carlo simulations for the calculation of Range are based on the so-called Continuous Slowing Down Approximation (CSDA). In this approximation, it is assumed that the particle loses its energy in a continuous way and at a rate equal to the stopping power. Since the stopping power is the energy loss of projectile per unit path, CSDA range (or Bethe range) is calculated by

$$R(E) = \int_{E_{abs}}^E \frac{dE'}{S(E')}$$

where E_{abs} is the energy where particle is effectively absorbed. CSDA range is the path length traveled by the particle and since energy-loss fluctuations are not considered, CSDA range is always higher than projected range (R_p) which is the distance between the point where particle enters the stopping medium and the point where particle is absorbed (or come to rest). It becomes important when the projectile's energy is low enough.

SRIM uses PRAL (**P**rojected **R**ange **A**lgorithm) [6] equations for calculating projected range. To second order it involves iterating the difference equation

$$R_p(E_0 + \Delta E_0) = R_p(E_0) + \left[\frac{4E^2 - (2E\mu S_n + \mu Q_n)R_p(E_0)}{4ES_t - 2\mu Q_n} \right] \frac{\Delta E_0}{E}$$

Test Results for Protons

We calculated the stopping powers and ranges of H (Gas), Pb (solid) and water (Liquid) for protons and compared the results with PSTAR.

Protons on H (Gas)

As can be seen in fig. 1, overall agreement with PSTAR is quite good. Comparing the RANGE module's results with PSTAR, the overall mean error in energy range from 1 keV to 1 GeV is 0.8 %, mean error is 1.8 % in energies below 400 keV and mean error in energies below 10 keV is 2.5 %.

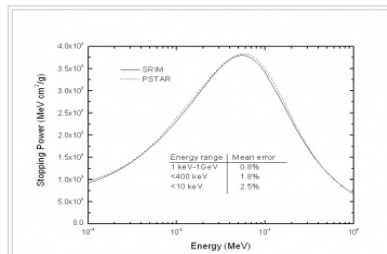


Figure 1. The stopping power results for protons in H (Gas)

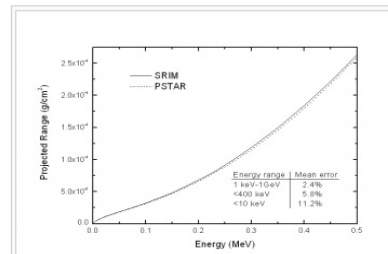
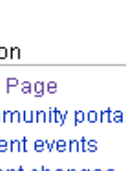


Figure 2. The range results of protons in H (Gas).



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Help:Range & Stopping Power

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Range and Stopping power

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7 Using Range&Stopping Power Module

Range & Stopping Power in Nucleonica

The RANGE module:

- provides a user-friendly interface for quick and accurate calculations on the range and stopping powers of charged particles.
- can calculate SP and Range for electrons, positrons, protons, alphas, muons and heavy ions in a variety of different natural elements, pre-defined and user-defined compounds.
- give freedom to the user for selecting the energy and stopping power units.
- provides high quality graphs for SP and Range.
- can be used in the Nucleonica scripting language.
- Test results show agreements of less than 5% for protons and alphas, less than 10% for electrons and positrons, and less than 7% for muons for the total stopping powers and the CSDA Ranges. The Range module uses SRIM for heavy particles with a known accuracy of less than 5%.

Range & Stopping Power in Nucleonica

EXERCISES

Q1: What must be the minimum thickness of a shield made of (a) Plexiglas and (b) aluminum in order that no beta rays from a ^{90}Sr source pass through?

SOLUTION:
Firstly, we must know the decay chain for ^{90}Sr .
Go, Applications>Decay Engine

The left screenshot shows the 'Decay Engine' window with the 'Parent+Daughters' table. The table has three columns: 'Parent+Daughters', 'Decay', and 'A(Bq)'. The rows are:

Parent+Daughters	Decay	A(Bq)
38 Sr90	β-	5.00E+02
39 Y90	β-	5.00E+02
40 Zr90 Stable		0
Total:		1.00E+03

The right screenshot shows the 'Decay Engine' window with the 'Options' tab selected. The 'Quantity' is set to 'Grams' and '1'. The 'Time' is set to 'Years' and '2.88E+02'. The 'Accuracy Factor' is '1E-02'. The 'Number of timesteps' is '10'. The 'Number of chains' is '1'. The 'Start' button is circled in red. The 'Type of graph' is set to 'Numbers'.

Range & Stopping Power in Nucleonica

What is the energies of beta rays from ^{90}Sr and ^{90}Y ?
Go Data>Nuclide Datasheet

Element:

Mass:

Sr

90

Datasheet

Description

Derived Data

Average Cross Sections

Radiations

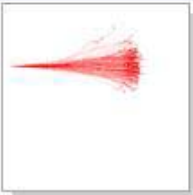
Prompt Gamma

Select Print Outputs

» Reference Data Notes

Density	2.64 g/cm ³		
Mass Excess	-85941.604 (± 2887) keV		
Atomic Mass	89.907737888 (± 3099) u		
Half-life	28.79 (± 6) y		
Spin	0 ħ		
Parity	+		
Binding Energy	8.69590 MeV/nucleon		
Abundance	-		
Effective Dose Coefficient Inhalation	1.6E-07 (Sv/Bq)		
Effective Dose Coefficient Ingestion	2.8E-08 (Sv/Bq)		
Mean Decay Energies			
Alpha	0 (MeV)		
Electron	174 (keV)		
Photon	0 (keV)		
Type of decay	Branching Ratio	Decay Energy, Q	Daughters
β-	1	0.546 (MeV)	39 Y 90

Range & Stopping Power in Nucleonica



Range & Stopping Power

Questions, remarks, suggestions can be posted in the [forum](#)

Input

Details

Compound Details

Options

Table

Input

Projectile

Projectile Details

Projectile Ion

electron

Energy (MeV)

2.28

Target

Density (g/cm³)

Aluminum

2.702

☒ Mono-element

☐ Predefined compound

☐ User defined compound

☒ Solid/Liquid

☐ Gas

Run

Results

electrons on Aluminum

CSDA Range, R:

5.094E-1 cm


Mass thickness:

1.376E+0 g/cm²

Stopping Power (total):

1.549E+0 keV/(mg/cm²)

Range & Stopping Power in Nucleonica



Range & Stopping Power

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Input

Details

Compound Details

Options

Table

Input

Projectile

Projectile Details

Projectile Ion

electron

Energy (MeV)

2.28

Target

Density (g/cm³)

Plexiglass

1.17

☐ Mono-element

☒ Predefined compound

☐ User defined compound

☒ Solid/Liquid

☐ Gas

Run

Results

electrons on Plexiglass

CSDA Range, R:

9.181E-1 cm

Mass thickness:

1.074E+0 g/cm²

Stopping Power (total):

1.946E+0 keV/(mg/cm²)

Range & Stopping Power in Nucleonica

Q2:What thickness of aluminum foil is required to stop the alpha particles from ^{210}Po ?

Hint: Check the decay chain of Po-210, then find the maximum energy of the alpha particles emitted in the chain.

SOLUTION:

Po210
1.4E2 d

Decay engine

84 Polonium

Current Chart: Karlsruhe

Element: Po Mass: 210

Decay Engine Options

Quantity: Grams 1 Accuracy Factor: 0.01

Time: Years 3.78893 Number of timesteps: 10 Number of chains: 1

Start Start in background Reset Show details

Parent+Daughters	Decay	A(Bq)	A.beta-(Bq)	Is.Power(W), $\alpha+\beta$
84 Po210	α	1.63E+11	0	1.41E-01
82 Pb206 Stable		0	0	0
2 He4 Stable		0	0	0
Total:		1.63E+11	0	1.41E-01

No, Radioactive daughter


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Data>Nuclide Datasheet

Element: Mass:

Po 210 

Reference Data

Description

Derived Data

Cross Sections

Radiations


Prompt Gammas

Select Print Outputs

[» Reference Data Notes](#)

Density	9.20 g/cm ³		
Mass Excess	-15953.071 (± 1242) keV		
Atomic Mass	209.982873673 (± 1333) u		
Half-life	138.388 (± 4) d		
Spin	0 ħ		
Parity	+		
Binding Energy	7.83435 MeV/nucleon		
Abundance	-		
Effective Dose Coefficient Inhalation	4.3E-06 (Sv/Bq)		
Effective Dose Coefficient Ingestion	1.2E-06 (Sv/Bq)		
Mean Decay Energies			
Alpha	5.40752 (Mev)		
Electron	9.32726E-05 (keV)		
Photon	0.00972462 (keV)		
Type of decay	Branching Ratio	Decay Energy,Q	Daughters
α	1	5.40745 (MeV)	82 Pb 206

Range & Stopping Power in Nucleonica



Range & Stopping Power

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Input

Details

Compound Details

Options

Table

Input

Projectile

Projectile Details

Projectile Ion

alpha

Energy (MeV)

5.4

Target

Density (g/cm³)

Aluminum

2.702

☒ Mono-element

☐ Predefined compound

☐ User defined compound

☒ Solid/Liquid

☐ Gas

Run

Results

alphas on Aluminum

Projected range, R:

Mass thickness:

Stopping Power (total):

2.425E+1 μm

6.552E-3 g/cm²

5.758E+2 keV/(mg/cm²)

Range & Stopping Power in Nucleonica

Q3: What are the energies of ^{12}C ions to implant to 1mm depth in SiO_2 sample?

SOLUTION

Range & Stopping Power

Input Details Compound Details Options Table

Input

Projectile

Projectile Ion: C

Energy (MeV): 5.4

Target: SiO_2

Density: 2.634

Run

Range & Stopping Power

4.470E+0 μm
1.177E-3 g/cm^2
5.723E+3 $\text{keV}/(\text{mg}/\text{cm}^2)$

Calculation using SRIM-2006
SRIM version --->
Calc. date ---> October 02, 2010

Diak File Name = range_out2.txt

Ion = Carbon [6], Mass = 12 amu

Density = 2.634E+00 $\text{g}/\text{cm}^3 = 7.3199\text{E}+02$ atoms/cm3

===== Target: Composition: =====

Name	Atom	Atom	Atomic	Mass
			Percent	
O	8	066.67	533.26	
Si	14	283.33	1444.74	

Energy Correction = 0.004
Stopping Units = $\text{keV}/(\text{mg}/\text{cm}^2)$
See bottom of Table for other Stopping units

Ion = Carbon [6], Mass = 12 amu

Ion Energy	dE/dx Elec.	dE/dx Nuclear	Projected Range	Longitudinal Straggling	Lateral Straggling
999.999 keV	1.101E-02	5.916E-02	42.4 μm	28.4 μm	20.4 μm
1.10 keV	1.208E-02	5.701E-02	43.4 μm	30.4 μm	21.4 μm
1.20 keV	1.269E-02	5.772E-02	46.4 μm	31.4 μm	23.4 μm
1.30 keV	1.314E-02	5.833E-02	49.4 μm	33.4 μm	24.4 μm
1.40 keV	1.364E-02	5.895E-02	52.4 μm	35.4 μm	25.4 μm
1.50 keV	1.412E-02	5.956E-02	55.4 μm	36.4 μm	26.4 μm
1.60 keV	1.458E-02	5.970E-02	58.4 μm	38.4 μm	28.4 μm
1.70 keV	1.503E-02	6.004E-02	61.4 μm	40.4 μm	29.4 μm
45.00 keV	2.707E-03	1.803E-01	44.87 μm	1.55 μm	8948.4 μm
50.00 keV	2.564E-03	1.460E-01	52.04 μm	1.88 μm	7684.4 μm
55.00 keV	2.412E-03	1.342E-01	59.67 μm	2.18 μm	8487.4 μm
60.00 keV	2.277E-03	1.243E-01	67.76 μm	2.47 μm	9295.4 μm
65.00 keV	2.157E-03	1.158E-01	76.32 μm	2.75 μm	1.02 μm
70.00 keV	2.048E-03	1.084E-01	85.35 μm	3.04 μm	1.11 μm
80.00 keV	1.881E-03	9.628E-02	104.79 μm	4.12 μm	1.30 μm
90.00 keV	1.738E-03	8.670E-02	126.10 μm	5.12 μm	1.52 μm
100.00 keV	1.573E-03	7.893E-02	149.23 μm	6.59 μm	1.75 μm
110.00 keV	1.465E-03	7.246E-02	174.32 μm	7.95 μm	2.00 μm
120.00 keV	1.383E-03	6.707E-02	201.22 μm	9.04 μm	2.27 μm
130.00 keV	1.278E-03	6.243E-02	229.99 μm	9.93 μm	2.55 μm
140.00 keV	1.202E-03	5.842E-02	260.61 μm	10.54 μm	2.85 μm
150.00 keV	1.136E-03	5.493E-02	293.00 μm	11.09 μm	3.17 μm
160.00 keV	1.079E-03	5.183E-02	327.40 μm	12.10 μm	3.51 μm
170.00 keV	1.023E-03	4.908E-02	363.57 μm	13.16 μm	3.86 μm
180.00 keV	9.780E-04	4.660E-02	401.57 μm	14.24 μm	4.23 μm
200.00 keV	8.918E-04	4.241E-02	482.95 μm	18.37 μm	5.33 μm
225.00 keV	8.070E-04	3.814E-02	594.85 μm	24.30 μm	6.12 μm
250.00 keV	7.384E-04	3.489E-02	717.79 μm	29.85 μm	7.31 μm
275.00 keV	6.820E-04	3.183E-02	851.69 μm	35.49 μm	8.61 μm
300.00 keV	6.357E-04	2.945E-02	995.59 μm	41.00 μm	10.00 μm
325.00 keV	5.971E-04	2.737E-02	1.15 μm	46.51 μm	11.49 μm
350.00 keV	5.648E-04	2.559E-02	1.31 μm	52.02 μm	13.07 μm
375.00 keV	5.368E-04	2.414E-02	1.49 μm	57.65 μm	14.73 μm
400.00 keV	5.085E-04	2.288E-02	1.67 μm	63.14 μm	16.47 μm

Range & Stopping Power in Nucleonica

Q4: Consider the case of fluence of 10^{10} /cm² 10 MeV electrons incident on a Pb layer 1mm thick. Calculate the mean dose deposited by electrons.

SOLUTION

Mean dose deposited by the electrons is given as $D=1.602 \times 10^{-10} \times S_e \times \Phi$
Here S_e is collisional stopping power in units MeV/g/cm² and Φ is the fluence in 1/cm². So, dose can be obtained as Gy.

Range & Stopping Power

Input Details Compound Details Options Table

electrons on Lead

Energy (MeV): 10

CSDA Range, R: 5.715E-1 cm

Mass thickness: 6.482E+0 g/cm²

S(electron): 1.128E+0

S(radiative): 1.157E+0

S(total): 2.285E+0

Stopping power S unit: keV/(mg/cm²)

Radiation Yield: 3.298E-1

Questions, remarks, suggestions can be posted in the forum

$$S_e = 1.128 \text{ keV/mg/cm}^2 \text{ (MeV/g/cm}^2\text{)}$$

$$D = 1.602 \times 10^{-10} \times 1.128 \times 10^{-10} = 1.807 \text{ Gy}$$

Thanks!



nucleonica

